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LOSS OF CABIN PRESSURE IN CANADIAN FORCES EJECTION SEAT AIRCRAFT 1962 TO 1982

C.J. Brooks

Defence and Civil Institute of Environmental Medicine
1133 Sheppard Avenue West
P.O. Box 2000
Downsview, Ontario M3M 3B9

DEPARTMENT OF NATIONAL DEFENCE - CANADA

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ABSTRACT

A review of all aircraft accidents and incidents in the Canadian Forces over the last 20 years (1962 - 1982) has been carried out. There have been 47 cases of serious loss of cabin pressurization in ejection seat equipped aircraft. Altitudes varied from 15,000 to 54,000 feet. No one aircraft appears to be more vulnerable. The most common cause was problems with the canopy seal (25%). There were three cases of hypoxia and two cases of decompression sickness. No deaths or permanent injuries occurred. Loss of pressurization is an extremely low, but definite risk to the pilot and aeromedical training with practical demonstration in the hypobaric chamber should continue. This report has been published in Aviation Space and Environmental Medicine. 55:1154-63, 1984.

1. INTRODUCTION

With the advent of the low differential pressurized cockpit for which standards were established in about 1945 (2,3,4), one of the hazards that face the military aviator in ejection seat aircraft is loss of cabin pressure or decompression. The causes can be generally divided into four categories - partial or complete loss of canopy (battle damage, birdstrike, fatigue, inadvertent release); mechanical failure of latching; failure of the canopy seal; and finally flame-out or malfunction of the pressurization system itself.

Decompression presents a pilot at altitude with four immediate problems in order of priority - hypoxia; expansion of gas in the middle ear, paranasal sinuses and gastrointestinal tract; decompression sickness; and exposure to cold outside ambient air.

The objective of this study was to determine the frequency of depressurizations, to analyse the physiological problems related to decompression, to note how well the oronasal mask and oxygen regulator functioned and to identify any trends that may have occurred by aircraft type, altitude and geographical location. This information is a valuable aid in planning R&D in oxygen equipment for the late 1980s and style of aeromedical training.

2. SOURCES OF INFORMATION

The literature at DCIEM was reviewed, but a summary of decompression incidents involving Canadian aircrew was not found. The most recent data is documented firstly by the USAF (1960 to 1964) who had an average of 94 decompressions per year and incidents of 2.4 per 100,000 hours on all types of aircraft (2), and secondly by the RAF who in 1964 reported "having eight anoxic incidents on fighter aircraft using low differential cabins in the past three years and 55 oxygen system malfunctions in the past two years" (1).

All CF accidents/incidents that have occurred since 1 January 1962 were reviewed with the assistance of the computer at NDHQ/DFS. It was used to search through 462 A, B and C category accidents in ejection seat aircraft back to 1 January 1962, and 17,552 incidents back to 1 January 1966. To confirm accuracy and completeness of the information compiled, it was circulated to as many current and retired aircrew as possible.

3. RESULTS

3.1 General

The initial survey identified 24 decompression incidents and subsequent circulation of this information identified an additional 23 incidents. These are listed in Table 1 by date, location, aircraft type and altitude at which they occurred. For ease of discussion, each is assigned a Case Number.

Factors affecting the physiological response are initial and final altitudes and rate and time of decompression.

Teachers in aviation medicine generally recognize four categories of decompression. Very slow leaks; slow loss of pressure; rapid loss of

pressure; and finally massive/explosive decompression (1). However, due to the fact that the majority of the information on the earlier accidents which was reviewed lacked specific detail and that there has been little Flight Surgeon consultation in any of the incidents, it was impossible to establish the rate of decompressions, or whether aerodynamic suction contributed to the final altitude. As a result, three categories have been used - massive loss of cabin pressure; slow loss of cabin pressure; and an intermediate category. This has been assigned to cases where existing data is inadequate to assign them to either of the first two categories. The scenarios presented suggest that these cases could be categorized between the two extremes.

3.2 Description of Incidents

There were 29 incidents where loss of pressure was massive/explosive (Table 2), 13 incidents of slow cabin pressure loss (Table 3) and five which were in the intermediate category (Table 4). The next section covers a summary of each incident, by rate, category as defined above and aircraft type;

3.2.1 Massive Loss of Cabin Pressure

CT133 (Silver Star)

Ten CT133 aircraft have had either cracks, breaks or loss of the canopy. The first pilot (Case 1) had taken a student up for a two-plane training mission from CFB Portage La Prairie (Manitoba); at 15,000 feet and 270 knots, the canopy seal failed. Unfortunately, the student in the process of checking that the canopy was locked, moved the lever the wrong way and jettisoned the canopy. His testimony describes the subsequent events very well.

> "For a matter of ten seconds, I just sat there. My helmet had been ripped off instantly (my head was turned slightly to the side and my seat was about half way between full-up and full-down) and I found it very difficult to open my eyes due to the wind blast and the dirt being blown out of the cockpit. Then, I moved the seat to the full-down position and began tightening my harness and oxygen mask. I then noticed that a check list had been blown from the clip on my left knee. The wind blast was not nearly as severe in the front with the seat down, so I offered to fly the aircraft back to the base. But the instructor who had already declared an emergency, kept control and flew it back at speeds ranging from 210 K to 195 K."

The second incident (Case 2) involved a pilot who was on a ferry flight from CFB Portage La Prairie (Manitoba) to Kenora, Ontario. On reaching 35,000 feet, his canopy suddenly split from rail to rail and he made an uneventful emergency landing at CFB Portage La Prairie. As a result, he suffered from otitic barotrauma.

The third incident (Case 3) occurred when two pilots were returning to 4 Wing (Baden-Soellingen, Germany) from the Air Weapons Training Unit at Decimomannu, Sardinia. While flying at 35,000 feet above cloud at night 40 minutes after take-off, they experienced explosive decompression. Due to pressure breathing, windblast and noise, the pilots were unable to communicate on the intercom until the aircraft had descended to 28,000 feet and the airspeed was reduced to 195 kts. It was then determined that a portion of

the canopy at the rear left side had blown out. As communication with the French control was restored and the only aircraft problems appeared to be the loss of heat and pressurization, they decided to continue on to their destination rather than make a night weather diversion into a French base. The aircraft landed at 4 Wing without further problems. Post-flight inspection revealed a hole approximately three feet square in the rear of the canopy. There was a comment that no reports were received to date of ground damage from missing pieces of canopy or one officer's cap which were sucked out of the cockpit!

In the fourth incident, the pilot (Case 4) was enroute from CFB Rivers (Manitoba) to CFB Ottawa when the cockpit suddenly decompressed after his canopy split at 37,000 feet. As the reason for this was undetermined and there were no further comments in the file, one can only assume that he made an uneventful landing.

The next three incidents were all caused by split canopies. A pilot on a training flight, 42 miles south of CFB Moose Jaw (Saskatchewan) experienced a decompression at 32,000 feet after the rear half of his canopy disintegrated (Case 5). A pilot on cross-country training between the Lakehead and Kapuskasing (Ontario) had a split canopy at 33,000 feet (Case 6), and a pilot experienced a decompression at 35,000 feet 75 miles east of Saskatoon (Saskatchewan) when his canopy split from rail to rail (Case 7). There were no comments in these Boards of Inquiry about aeromedical or life support equipment problems.

The eighth incident in this category (Case 9) involved a pilot and navigator who were enroute from CFB Toronto (Ontario) to CFB Rivers (Manitoba) when the navigator inadvertently jettisoned the canopy at 35,000 feet. One hundred per cent oxygen and safety pressure was selected and an immediate descent was made into Kenora, Ontario. An approach could not be made, so the pilot elected to fly at 10,000 feet for a further 30 minutes and land at CFB Winnipeg (Manitoba). From personal communication with the pilot, even with his visors down and his head kept well below the canopy rail, he still had some residual cold injury to his face and conjunctiva for about a week. The navigator suffered from a small laceration on the right cheek as a result of a split helmet visor.

Poor human engineering contributed to the ninth incidence (Case 10) which was similar to the occurrence in Case 1. The student was flying out of CFB Gimli (Manitoba) at 20,000 feet when something caught his eye. He thought the canopy had become insecure and reached down to check the lever. Unfortunately he moved it the wrong way, so jettisoning his canopy and causing rapid decompression. As a result he suffered from conjunctivitis (a result of the windblast and dust).

The tenth and last CT133 pilot to have a very rapid decompression (Case 11) was enroute from CFB Cold Lake (Alberta) to CFB Winnipeg at 33,000 feet when his canopy cracked, probably from fatigue. He returned to base with no further problems.

<u>CF100 (Canuck)</u> .

Four CF100 aircraft have had sudden loss of pressure. The first incident (Case 14) happened to two pilots who were on a final clear-hood mission 30 miles north of CFB Bagotville. They were proceeding at 325 knots

at 17,000 feet when suddenly, for no apparent reason, the canopy slid back exposing them to a sudden blast of air and dust. The reason for this incident still remains obscure. They declared an emergency and returned to base with no further problems.

The second incident (Case 15) was caused by an air pressure regulator which failed in the Ottawa area at 40,000 feet. The pilot experienced an initial slow leak to 31,000 feet and then a rapid loss to ambient. The aircraft returned to base without further incidents.

The third incident (Case 16) happened to a pilot and navigator who were flying at 20,000 feet 60 miles north of Andrews AFB (Maryland) on an air defence exercise. Due to the progressive breakdown in the canopy external holding switch, the canopy suddenly opened in flight. No further comments were included with this incident, so it is assumed the aircraft made an uneventful emergency landing.

The fourth aircraft (Case 18) experienced a sudden decompression following a canopy seal failure at 39,000 feet, 100 miles north of Ottawa. Both crew experienced some breathing difficulty. An immediate descent to 10,000 feet was made and the aircraft was landed with no further incident.

CF 101 (Voodoo)

Four CF 101 crew have experienced sudden pressure loss. The first incident (Case 19) was yet another result of poor human engineering. The pilot and navigator were on an air defence mission 60 miles north east of Ottawa at an altitude of 35,000 feet when the navigator reached over to switch on his identification light and operated the canopy jettison lever by mistake, resulting in sudden decompression. The pilot's testimony describes the incident precisely:

> "When the canopy blew my first reaction was to look around and see what had happened and this is where I received my initial shock because everything was enveloped in a grey haze and I could not see anything. Added to this was the wind blast on my eyes and dirt from the floor of the cockpit which had temporarily blinded me. I could hear the navigator shouting at me to get the a/c down, so I put my visor down, pressed my head against the instrument shield and commenced a rapid descent to 10,000 feet. The visor gives only a little relief from the wind blast and my eyes were smarting from the dirt present in them. The blast effect could be described as similar to sticking one's head out of a car doing over 100 mph. Communication between cockpits was a problem at first because the wind noise blanked out our voices. We corrected this by tightening our masks and on reaching 10,000 feet slowing the a/c to 250 knots IAS. At this time we went to 243 mcs and called Ottawa Arrival. Both my navigator and I were quite warm throughout the whole effort and since the wind blast effect at 220 knots is almost negligeable compared to what we had previously experienced no more problems were encountered in making a normal landing at base.
>
> Just a few points to consider. Initially you will be temporarily blinded but after a few seconds, partial vision will return and despite a soreness in the eyes which will persist throughout the trip, vision will steadily improve to normal once speed has been

reduced to approach speed. Do not rub your eyes because more likely than not, most of the 'crud' is iron filings which are present in the cockpit. Rubbing them will not only aggravate the eyes but probably damage them more than they are already."

The navigator's comments were also equally important to quote for use by anyone involved in aeromedical training:

> "Wind blast effect in the rear seat was quite bearable when hunched over. I did sit up once, and the only effect I noticed was that my visor, which had been down, got forced up. When the visor was down, there was a lot of air blowing through between the visor and my head. I am under the impression that rather than actual wind blast, what you feel is a wind burble over the blast shield. I seemed to be well protected from the direct wind blast. There must be a terrific down draft along the sides though, because I had a package of cigarettes and a fairly heavy lighter in my left sleeve pocket, with the zipper done up. Somehow, that zipper came down, and the cigarettes and lighter disappeared, while the contents of the right-hand pocket were still there on landing."

The second incident (Case 20) was another inadvertent jettison of the canopy by the navigator. The crew were carrying out an operational attack at 32,000 feet, 40 miles southwest of Chatham, New Brunswick. While the aircraft was in a hard starboard turn at 510 knots, severe buffeting was experienced. The navigator was not wearing his left glove, and his wrist watch caught the canopy jettison handle during the severe negative G induced by the buffet. The aircraft recovered to Chatham with no further problems except that the pilot had otitic barotrauma and the navigator had a bruise on the left hand from contact with the canopy jettison lever.

The third incident (Case 22) was another one related to poor human engineering, identical to Case 19. The navigator inadvertently activated the canopy jettison device when feeling for his identification light. This occurred at 15,000 feet 110 miles northwest of Chatham. The aircraft was recovered with no further problems.

The fourth incident (Case 26) happened to the crew of a CF101 midway between Bermuda and CFB Bagotville, Quebec, at 37,000 feet when the canopy seal failed. The leak was temporarily stopped by stuffing a helmet bag into the leak. This maintained the cabin at 27,000 for several minutes until total loss of pressure was experienced. No problems were encountered until 60 miles SSE of Bangor, Maine, when the navigator developed tingling in the left arm and both knees. A diagnosis of the "bends" was made. A request for a lower altitude was approved and the navigator's symptoms disappeared. As a result, the crew continued to an uneventful landing at Bagotville.

CF116 (Freedomfighter)

One CF116 pilot (Case 28) doing a full card air test over CFB Cold Lake, at 250 kts and an altitude of 25,000 feet, lost the rear canopy of the aircraft due to the canopy thruster device being improperly installed. He came straight in to a full stop with no further problems.

CF104 (Starfighter)

Eight CF104s have had sudden loss of cabin pressure. The first incident (Case 29) occurred to a pilot on a full engine test run at CFB Cold Lake. At 36,000 feet and Mach 1.4, pressure was sudden lost due to a maladjusted canopy seal locking lever. The aircraft made an uneventful recovery.

The second incident (Case 30) occurred on another test flight out of CFB Cold Lake. At 35,000 feet and Mach 2.0, pressure was suddenly lost due to a badly adjusted canopy microswitch. The aircraft was recovered with no further problems.

The third incident (Case 31) occurred to a pilot on a training mission out of CFB Cold Lake. On climb out (no altitude was given in the report) at 450 knots, pressure was suddenly lost due to a loose canopy striker bolt. The aircraft returned to base with no further incidents.

The fourth incident (Case 32) was another mechanical problem with the canopy which caused decompression. At 20,000 feet and 360 knots, the pilot flying out of CFB Cold Lake experienced a decompression due to the maladjustment of the canopy switch and spring tension on the canopy locking lever. The aircraft was again recovered without further incident.

The fifth incident (Case 35) happened to a pilot who was on a NORAD exercise 90 miles north of Malstrom AFB Montana at 33,000 feet. He experienced a sudden decompression due to a canopy seal rupture. The violence was enough to pop several circuit breakers and as a result he had to do an emergency flapless landing.

The sixth incident (Case 36) happened at CFB Baden (Germany) during a test flight at 36,000 feet and an IAS of Mach 1.9. Pressure was suddenly lost due to a maladjusted canopy striker bolt. The pilot throttled back, put out speed brakes and the cabin repressurized. The aircraft returned to base with no further incidents.

The seventh incident (Case 39) happened to an aircraft on an air test at an altitude of 36,000 feet at Mach 2 over CFB Baden. Pressure was suddenly lost, speed was reduced from Mach 1.7 and an immediate uneventful return to base was executed. The cause of the incident was a maladjusted canopy warning switch.

The eighth incident (Case 40) was a maintenance air test out of CFE Detachment, Baden. Personal communication with this pilot is quoted in full:

> "The incident occurred during the Mach 2 run at 37,000 feet as the Mach 1.8 engine parameters were being recorded. Subsequent investigation revealed that the bonding which attaches the plexiglass to the metal canopy frame had separated. The result was a shattered canopy with shards of plexiglass left attached to the frame. These pieces of canopy caused me some concern during the return to base. Decompression was rapid but not explosive [the author categorized this as massive decompression] - my immediate reaction was to decelerate. As the aircraft was decelerated through approximately Mach 1.4, the papers on my knee pad were blown free. They did not leave the cockpit immediately, but were blown around in front of my face for some time.

Decompression was well completed before the aircraft was subsonic. The bail-out bottle was activated. Immediate personal concerns were oxygen, keeping my hands within the cockpit so that the slipstream would not grab them, and aircraft damage. A descent was initiated when the aircraft was subsonic. Engine performance was checked during the descent. A slow speed controlability check was conducted below 10,000 feet ASL. At normal approach speeds a severe buffet occurred at my head and shoulders, so the approach and landing were flown at higher than normal speeds to avoid the buffet. Communication with ATC was difficult because of the bail-out bottle pressure and noise. No additional problems can be recalled. Retrospectively, it was probably unnecessary to activate the bail-out bottle which caused communication difficulties. Also my concern about my hands being caught by the slipstream was unnecessary because wind was not a problem. The reported cold temperature at altitude was not a factor. As a matter of fact I think I may have been perspiring!"

F86 (Sabre)

Two F86 Sabres have had a very rapid loss of pressure. The first incident (Case 46) occurred to a pilot of the Golden Hawk Aerobatic Display Team while on the way to an air show. After take off and climb out over Edmonton (altitude not stated), he reached down to adjust his seat. Much to his surprise he jettisoned the canopy. Examination of the seat (after an uneventful recovery) revealed that there was insufficient clearance between a bolt on the seat and the right hand console. Adjusting the seat had rotated the R.H. canopy ejection handle upwards.

The second F86 incident (Case 47) occurred out of Chatham during a full power air test at Mach 0.82. The canopy suddenly opened approximately 12 inches and then slammed shut, causing the cabin to decompress rapidly to 30,000 feet. The startled pilot made an uneventful recovery. Cause of the incident was obscure, but the most likely cause was considered to be that some part of the pilot's equipment caught on the canopy release lever.

3.2.2 Slow Loss of Cabin Pressure

CT133 (Silver Star)

There was only one CT133 in this category (Case 8). The crew were flying at 39,000 feet north of the Tango TACAN at CFB Lahr, Germany, when the rear pilot suddenly noticed pressure in his mask. The aircraft captain checked and found the cabin altitude was 35,000 feet. No further comments were made on this case, so presumably an uneventful recovery took place. The cause of the leak was a canopy seal failure.

CF100 (Canuck)

There were two CF100s in this category. The first incident (Case 12) occurred to a pilot and navigator on an air defence attack out of CFB Comox (British Columbia). At 38,000 feet and a cabin altitude of 21,000 feet, the pressure started to leak and was noticed to have reached 27,000 feet. At this point the pilot experienced hot and cold flashes. One hundred percent oxygen and safety pressure were selected and the pilot felt better after several boosts of oxygen via the "press-to-test" button. The aircraft was recovered with no further problems. The cause of the incident was obscure.

No reason was found for the loss of pressurization, although the regulator was found to be unserviceable and contributed to the pilot's symptoms of hypoxia.

The second incident (Case 17) happened on climb out (final altitude not reported) to a pilot who noticed that the "pressure had failed". He descended to 6,000 feet, could not rectify the problem and so returned to CFB Comox. On Landing, it was found that the canopy seal had jammed in the canopy rail and it took four people to release it!

CF 101 (Voodoo)

There were four CF 101s in this category. The first incident (Case 21) was rather similar to the CF 100 in Case 12. The pilot was flying at 32,000 feet when he felt light-headed and noticed that his cabin pressure had dropped to 27,000 feet. He returned safely to CFB Bagotville. Subsequent investigation revealed that the canopy seal was cut and the oxygen regulator was suspected unserviceable. Unfortunately the records do not establish whether this was true or not.

The second incident (Case 23) happened to a pilot who was passing through 20,000 feet out of Val D'Or (Quebec). Pressure was lost and an uneventful return to base was carried out. The cause of this incident was a cracked and bent canopy rail due to the pilot closing the canopy on the navigator's publication bag!

The third CF 101 (Case 24) was one in which the pilot was on a training mission in the Comox area at 25,000 feet when the canopy seal ruptured. One hundred percent oxygen was selected and the navigator noticed pain in his left arm. An immediate return to base was carried out, and the pain disappeared as altitude was lost.

The last CF 101 (Case 25) was a test flight at 40,000 feet from CFB Chatham, New Brunswick, when a gradual leak occurred to a cabin altitude of 30,000 feet due to the canopy seal becoming unseated. The navigator had developed pain in the left arm, 100% oxygen was selected, descent was initiated and the pain disappeared at 15,000 feet. On return, a diagnosis of Type I decompression sickness was made.

CF 104 (Starfighter)

Two aircrew have had a slower decompression. The first pilot (Case 37) was on a "low level training mission" over CFB Baden (no specific altitude mentioned), when he experienced loss of pressure due to fibreglass in the fresh air scoop lever and failure of the rain remover valve. He climbed to 20,000 feet when some pressurization was achieved, but this was soon lost and he returned to base.

The second pilot (Case 38) was also out of CFB Baden on a training flight at 30,000 feet when a two inch break in the air duct occured. If this was not enough, the IFF and TACAN became unserviceable and he had trouble feeding gas from the tip tanks. He made an uneventful emergency landing. Both canopies and the upper E-bay hatch had been left open in heavy rain conditions and moisture entered the electronics, which probably contributed to the malfunction.

Tutor (CT114)

The final four loss of pressure incidents all occurred in CT114s. The details on the first aircraft are vague (Case 42). The comments on the incident message stated that "just after take-off from CFB Gimli, Manitoba, the pressurization failed (no altitude stated) and smoke filled the cockpit". The cause of the problem was undetermined.

The second Tutor pilot (Case 43) was on a training solo out of CFB Moose Jaw who, on retarding the throttle at 25,000 feet, noticed the cabin pressure indicating 21,000 feet. The cause was a worn canopy seal. An uneventful return to base was carried out.

The third pilot (Case 44) was also on a training mission out of CFB Moose Jaw, when he levelled off at 15,000 feet and noticed that he had no cabin pressurization. The cause was a canopy seal leak, but again, the data available is so scanty that it is difficult to know whether he had pressurization from the start of the mission, or whether the aircraft followed ambient pressure from ground level to altitude.

The final occurrence (Case 45) was that of a pilot who experienced a slow leak at 17,000 feet following climb out from CFB Moose Jaw. The cause was a cracked canopy seal due to the severe cold weather.

3.2.3 Intermediate Rates of Loss of Cabin Pressure

CF100 (Canuck)

The first aircraft in this category (Case 13) was a CF100 at 33,000 feet, when the pilot experienced a decompression 85 miles east of CFB Winnipeg due to a worn canopy seal. The details in the report are extremely scanty and it is assumed the pilot made an uneventful recovery.

CF116 (Freedomfighter)

The second incident involved a CF116 pilot (Case 27) on a training mission at 18,000 feet who noticed the canopy unsafe indicator light up, and the aircraft cockpit immediately lost pressure. He landed at CFB Lahr with no problem. The cause was a bent canopy closing switch activating arm.

CF104 (Starfighter)

The third incident involved a CF104 pilot (Case 33) who also experienced a canopy closure switch de-activation at 15,000 feet over CFB Cold Lake, causing loss of pressure. An uneventful landing took place.

The fourth incident (Case 34) was a compound problem, rather similar to Cases 12 and 21. The pilot of a CF104 was on a handling familiarization Mach 2.0 run out of CFB Cold Lake. On completing the run at 35,000 feet, instead of slowing the aircraft by the normal procedures, he did a zoom climb to 54,000 feet. He suddenly felt ill, sweated profusely and felt tingling behind both knees. He noticed the cabin altitude was 40,000 feet, so he rolled inverted and commenced descent. He selected emergency oxygen but could feel no pressure, so he held the press-to-test button down while he descended. On safe recovery, the oxygen regulator was suspected to be unserviceable and the pilot's mask had the rubber seal missing from the MC3M

connector. No documentation was included in the report to confirm the regulator issue. The loss of pressure was due to an unserviceable cabin air pressure regulator.

In the last incident, another Starfighter pilot (Case 41) was doing a training mission over CFB Cold Lake when the canopy unsafe warning light came on due to a bent rear cockpit canopy bracket. This caused a decompression at 16,500 feet, and the pilot landed the aircraft without further incident.

3.3 CF101 Remarks

Further information was obtained specifically about the Voodoo aircraft through personal communication with one of the test pilots at the Aerospace Engineering Test Establishment (CFB Cold Lake). He revealed that the aircraft had been notorious for a large number of pressurization failures. Most were due to cut, broken or misaligned canopy seals, although many others occurred due to pressurization valve failures. The Voodoo history of seal problems most likely produced a situation where incidents were not reported unless hypoxia or other aeromedical problems were encountered (this would account for the fact that the Voodoo does not appear as the aircraft with the largest problem in the Directorate of Flight Safety Records). Furthermore, he stated that some pressurization loss would occur at a minimum of every 20 hours and he himself had experienced over 100 personal minor episodes of pressure loss in his 12 years experience and 2,000 hours of flying the aircraft. It was quite normal for aircrew to expect pressurization losses and helmet bags and flying gloves were often used in the early days of the aircraft to plug the leaks. Later on around 1969 chips of foam rubber were carried in the aircraft map cases for this purpose. Unreported incidents of slow leaks most likely occurred, thus a true index of this cannot be determined.

4. DISCUSSION

4.1 Causes of Loss of Cabin Pressure

Causes are displayed in Tables 2, 3 and 4. The most common reported cause (25%) was problems with the canopy seal either displaced, unseated, ruptured, torn, worn or leaking (12 incidents).

The next most common cause (23%) was problems with the mechanical latching of the canopy either thruster improperly installed, closure switch activating arm bent or deactivated, warning switch incorrectly adjusted or installed, canopy seal locking lever failed, or canopy striker bolt loose (11 incidents).

This was followed by nine incidents (19%) of problems with cracking or splitting of the canopy and/or rail, or failure of the bonding between the plexiglass and metal frame. The CT133, with seven incidents, is more prone to this probably due to advancing age.

There were eight incidents (17%) of inadvertent jettison of the canopy. Examined more closely, six of these were due to poor human engineering and general cockpit design. Specifically, two CT133 canopies were lost by the pilots who were checking to ensure that the canopy locking

lever was down, firm and locked. In the process of doing so, the lever was moved the wrong way and the canopies were jettisoned. In two incidents the navigator in the back seat of the CF101 operated the canopy jettison lever instead of the identification lightswitch and lost the canopy. A canopy of a CF101 was lost because a watch strap snagged in the jettison handle during severe buffet, and a similar incident happened to an F86 pilot who also lost the canopy, most likely because of interference between flying clothing and the release handle. The seventh case was caused by a bolt on the F86 aircraft seat with insufficient clearance with the right-hand console. When the pilot adjusted his seat, it operated the canopy release lever and jettisoned his canopy. Finally the last case was most likely due to the crew member who was a passenger touching knobs and switches which he should not have been handling.

Finally, there were four other causes namely undetermined (3 incidents), air pressure regulator failure (2 incidents), FOD in fresh air scoop (1 incident) and breakage of air duct (1 incident).

4.2 Life Support Equipment

All of the aircrew were wearing the standard A13A mask with Pate suspension. Sources of 1800 psi oxygen and the type of oxygen regulator installed are listed in Table 5. All regulators used were of the suction/pressure demand type providing protection from hypoxia to 50,000 feet and supplied 100% oxygen at a maximum pressure of 30 mmHg at this altitude.

There was one incident of an unserviceable oxygen regulator (Case 12) and two incidents where the oxygen regulator was suspected to be faulty (Case 21 and 34), but existing records neither deny nor confirm this suspicion. In the latter case, the oxygen mask was unserviceable due to the absence of the rubber seal on the MC3M connector. The pilot was extremely lucky to survive considering that he had reached an altitude of 54,000 feet (for which the oxygen regulator was never designed) where he had a loss of cabin pressure, which was compounded by a leaky mask hose.

In only two cases were any comments specifically made about the equipment. Firstly, in Case 8 the pilot experienced some difficulty in breathing when his CF100 canopy seal failed at 39,000 feet. It is reasonable to assume that the regulator as designed had started to deliver pressure into the mask which caused him to make the complaint. The second incident was in Case 40, where the CF104 pilot at 37,000 feet quite correctly realised after the event that activation of the bail-out bottle was unnecessary and caused him problems with communication due to the continuous oxygen flow. The regulator automatically senses the cabin altitude and provides the correct oxygen pressure. This incident is somewhat comparable to a rapid decompression that occurred in a British "V" bomber incident in 1959 (6). After the decompression each crew member set their regulators to the emergency position. The observations made after the event were that, firstly, the aircrew knew that this was not really necessary, but wanted to make sure they were getting oxygen at the correct pressure, and secondly, they were not really sure about the workings of their oxygen regulators. The lessons to be learned from this are that valuable time could be saved if this action is not taken, and unnecessary problems with communication would be avoided. These two practical examples of sudden decompression would be of use in re-emphasizing the principles of the oxygen system to aircrew.

4.3 Physiological Problems Encountered

4.3.1 General

The problems that could be expected from loss of pressure and did occur are listed in Table 6, and are discussed in four categories.

4.3.2 Hypoxia, Breathing and Communications

Three incidents of hypoxia have been reported. In each case the pilot recognized the symptoms and made the correct response (to initiate 100% oxygen, select safety pressure and make an immediate descent). In the case of the Canuck and the Voodoo (Cases 12 and 21), a relatively slow cabin de-pressurization had occurred. It was symptoms of hypoxia that alerted the pilots to the fact that all was not well. Theoretically, the oxygen regulator should have been able to provide the required air/oxygen mixture for cabin altitudes (27,000 and 32,000 feet respectively). Unfortunately the first regulator was unserviceable; the report of the condition of the second regulator is not in the records, but one could postulate that this was also unserviceable. Both pilots could have lost their lives from insidious hypoxia.

The third incident (Case 34) occurred to a CF104 pilot who decided to slow his aircraft down by doing a zoom climb following a Mach 2.0 handling mission at 35,000 feet, whereupon he reached 54,000 feet, felt unwell, broke out in a cold sweat and had tingling behind his knees, all classic symptoms of hypoxia. These alerted him to his complex problems of loss of cabin pressure due to a failed air pressure regulator from cabin pressurization. A suspected unserviceable oxygen regulator (never designed to operate above 50,000 feet) and an MC3M connector which when checked out at ground level had no rubber seal fitted and was thus not able to hold any pressure in his mask hose compounded the problems. This pilot was a lucky man indeed.

Two pilots of a CT133 (Case 3) which decompressed at 35,000 feet quite naturally had difficulty communicating due to pressure breathing, windblast and noise until they descended to 28,000 feet. This was an explosive decompresssion, so they probably experienced considerable aerodynamic suction, thus the final altitude was probably far greater than the ambient 35,000 feet.

Both pilots of a CF100 (Case 18) also quite naturally complained of breathing difficulties against the oxygen pressure when they were decompressed at 39,000 feet.

Finally there are the remarks of the pilot of the Voodoo (Case 19) who described the problems of tightening the mask and communications in the windblast very accurately and whose testimony provides excellent lessons for aeromedical training.

4.3.3 Expansion of Gases in Closed and Semi-Closed Cavities

There have been two incidents of otitic barotrauma. These occurred firstly to the pilot of a T33 whose canopy cracked at 35,000 feet from rail to rail causing an explosive decompression; and secondly to the pilot of a Voodoo who experienced severe buffeting in a hard starboard turn at 510

knots, and in so doing the navigators watch strap caught the canopy jettison handle so releasing the canopy at 32,000 feet (Cases 2 and 20).

4.3.4 Decompression Sickness

The pilot in the CF101 (Case 24) who developed pain in the left shoulder at 25,000 feet appears to have been correctly diagnosed as having decompression sickness, as was the navigator (Case 25) who developed pain in the left arm at a cabin pressure of 30,000 feet (ambient 40,000). However, there is reason to doubt the diagnosis of bends by the crew in the third Voodoo incident (Case 26) where the navigator had symptoms of "tingling in left arm and knees" which disappeared on descent. The problem was more likely attributable to hyperventilation. This crew was on a ferry flight at 37,000 feet from Bermuda to CFB Bagotville and mid-way through the flight, lost pressure. There must have been considerable anxiety during the re-planning their route at a lower altitude, so they tried to stop the leak with a helmet bag and managed to maintain a cabin pressure of 27,000 until they lost all pressure. Sixty nautical miles SSE of Bangor, Maine, the navigator complained of his symptoms. A lower altitude was selected and they realized then that they had sufficient fuel to complete the flight to Bagotville. The navigator's symptoms disappeared. Tingling is more a symptom of hyperventilation than of decompression sickness although DCS may effect three sets of joints simultaneously (3).

4.3.5 Cold Injury

Two cases of conjunctivitis have been reported due to a combination of cold, dust and wind. The first case (9) was that of the CT133 pilot who decompressed over Kenora and was unable to land due to poor weather. He chose to fly to CFB Winnipeg at 10,000 feet. Not unreasonably, he complained of very sore eyes from the cold for at least a week following the trip.

The second case (10) happened to the student who inadvertently jettisoned his T33 canopy when checking to insure it was locked. He lost his canopy at 20,000 feet and returned to Gimli with painful eyes.

4.3.6 Other Injuries

These have been very minor; a small cheek laceration from a split helmet visor (Case 9) and a bruise on the left hand from where a watchstrap caught the canopy jettison handle (Case 20).

5. CONCLUSIONS

This study is the largest and most detailed of any decompression incident series in ejection seat aircraft published to date to our knowledge, and it is concluded that:

a. Over this period of 20 years of peace time (1962 to 1982) there have been 47 cases of serious loss of cabin pressure - 29 massive or explosive decompression, 13 slower decompressions and five at an intermediate rate.

b. Decompressions have occurred in all types of ejection seat aircraft in service between 1962 and 1982; and no one aircraft appears more

vulnerable;

c. While the CF104 had the greatest number of reported incidents (13), followed by the CT133 (11), It is suspected that many Voodoo incidents were not reported;

d. The most common causes of depressurization are problems with the canopy seal (25%), canopy cracking (23%), the mechanical latching of the canopy (19%) and inadvertent release (17%).

e. Poor human engineering and cockpit design contributed to six (13%) inadvertent releases of the canopy.

f. No deaths or permanent injury can be attributed to sudden loss of cabin pressure, but there were two definite cases of decompression sickness, two minor cold injuries to the eyes and two cases of otitic barotrauma.

g. There were three cases of hypoxia, in which the pilots recognized their symptoms and followed established procedures leading to an uneventful landing which may be attributed to effective Aeromedical Training.

h. The oxygen mask and hose performed to specifications in all cases except one.

j. The oxygen regulator was unserviceable in one incident and possibly unserviceable in another two incidents.

k. Decompressions occurred in Canada, the U.S.A. and Europe, but there were no specific trends with respect to time of day, month or geographic location.

l. While aircraft altitudes at which decompression occurred varied from 15,000 to 54,000 feet, cabin altitude could not be precisely established in each case.

m. Loss of cabin pressure is an extremely low but definite risk to the pilot in ejection seat aircraft in peace time operation.

n. Flight Surgeons have rarely been consulted following a decompression incident.

o. Aeromedical training for loss of cabin pressure particularly experience in the hypobaric chamber is just as valid now as it was in 1962.

6. RECOMMENDATIONS

It is recommended that:

a. Aeromedical training for aircrew specifically with practical demonstrations in the hypobaric chamber continue.

b. Aircrew continue to be taught:

- the simple recognition of decompression sickness and the necessary corrective actions:

- the performance of oxygen masks and regulators, particularly the difficulty that will be experienced breathing and communicating while the regulator is providing oxygen under pressure at altitude in conjunction with noise, dust, windblast and cold.

c. NDHQ/DAS Eng-4 continue to emphasize to the Safety Systems Technicians the vital role that the oxygen regulator, mask and hose play in the prevention of hypoxia during decompression incidents and the penalties to be expected if equipment is poorly maintained in the field.

d. Operational Staff (i.e. Flight Safety Officers) consult Flight Surgeons after any decompression incident;

e. This report be used as a guide on which to base aeromedical training for aircrew in the late 1980s.

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8. REFERENCES

1. BAILES, W.D. and G.R. ALLEN. Cabin pressures for fighter aircraft. RAE Technical Memorandum No. Mech. Eng. 293. February 1964.

2. DHENIN: Aviation Medicine, Physiology and Human Factors Vol. 1, Chap 7, Trimed Books, UK 1978.

3. FRYER D.I. Subatmospheric Decompression Sickness In Man. Agardograph 125. Technivision Services, Slough, UK. April 1969.

4. LEACH and CARDWELL. Memorandum on the construction and operation of pressure cabin aircraft. RAE Report SME 3359, February 1945.

5. ROXBURGH, H.L. Physiological considerations on the choice of pressures for pressure cabin military aircraft. FPRC 402 (a). January 1945.

6. WAGNER, P.R. Report on Rapid Decompression in a "V" Bomber. RAF IAM Report No. 120 May 1959. Restricted.

Table 1. Altitudes, Dates and Positions of all Aircraft Decompressions

Case No.	A/C Type	Date	Altitude (Feet)	Position
1	CT133	27 Sep 63	15,000	Portage La Prairie, Man.
2	(Silver Star)	2 Jun 64	35,000	Portage La Prairie, Man.
3		14 Sep 67	35,000	Lyon, enroute Sardinia/Baden, Germany
4		4 Jul 68	37,000	enroute CFB Rivers Man./Ottawa Ont.
5		9 Jan 69	32,000	42 Miles S. Moose Jaw, Sask.
6		1 Mar 69	33,000	Between Lakehead & Kapuskasing, Ont.
7		20 Sep 69	35,000	75 miles E Saskatoon, Sask.
8		31 Oct 69	39,000	10 miles N Lahr, Germany
9		19 Mar 70	35,000	Kenora enroute Toronto (Ont)/Rivers, Man.
10		25 May 71	20,000	CFB Gimli, Man.
11		26 Feb 82	33,000	CFB Cold Lake enroute Winnipeg, Man.
12	CF100	16 Jan 62	38,000	CFB Comox, BC
13	(Canuck)	31 May 62	33,000	85 miles E Winnipeg, Man.
14		18 Oct 62	17,000	30 miles N Bagotville, Que.
15		30 Jun 67	40,000	100 miles N Ottawa, Ont.
16		3 Aug 67	20,000	60 miles N Andrews AFB (DC/USA)
17		12 Feb 71	Climbout	CFB Comox, B.C.
18		29 Jun 71	39,000	100 mi N Ottawa, Ont.
19	CF101	22 Feb 62	35,000	60 miles NE Ottawa, Ont.
20	(Voodoo)	5 Nov 64	32,000	40 miles SW Chatham, N.B.
21		28 Mar 66	32,000	CFB Bagotville, Que.
22		21 Nov 68	15,000	110 miles NW CFB Chatham, N.B.
23		26 Jul 73	20,000	Val D'Or, Que.
24		16 Jan 78	25,000	CFB Comox, B.C.
25		22 Sep 78	40,000	Chatham, N.B.
26		29 May 81	37,000	Midway Bermuda/CFB Bagotville, Que.
27	CF116	2 May 74	18,000	CFB Cold Lake, Alta.
28	(Freedomfighter)	6 Jul 78	25,000	CFB Cold Lake, Alta.
29	CF104	3 Mar 63	36,000	CFB Cold Lake, Alta.
30	(Starfighter)	8 Aug 63	35,000	CFB Cold Lake, Alta.
31		21 Jan 64	Climbout	CFB Cold Lake, Alta.
32		25 Feb 64	20,000	CFB Cold Lake, Alta.
33		8 Apr 69	15,000	CFB Cold Lake, Alta.
34		20 May 69	54,000	CFB Cold Lake, Alta.
35		18 Nov 70	33,000	90 mi N Malstrom AFB (MT/USA)
36		27 May 71	36,000	CFB Baden, Germany
37		7 Apr 72	Unknown	CFB Baden, Germany
38		26 May 72	30,000	CFB Baden, Germany
39		2 Feb 74	36,000	CFB Baden, Germany
40		22 Jul 75	37,000	CFB Baden, Germany
41		17 May 77	16,500	CFB Cold Lake, Alta.
42	CT114	18 Oct 68	Unknown	CFB Gimli, Man.
43	(Tutor).	5 Dec 72	25,000	CFB Moose Jaw, Sask.
44		18 Dec 72	15,000	CFB Moose Jaw, Sask.
45		15 Jan 74	17,000	CFB Moose Jaw, Sask.
46	F86	27 Jul 63	Unknown	CFB Namao, Alta.
47	(Sabre)	6 Jan 67	30,000	40 miles NW Chatham, N.B.

Table 2. Massive Loss of Cabin Pressure

Case No.	A/C Type	Date	Cause
1	CT133 (Silver Star)	27 Sep 63	inadvertent canopy jettison
2		2 Jun 64	canopy split rail to rail
3		15 Sep 67	3 ft piece of canopy blew out
4		4 Jul 68	split canopy
5		9 Jan 69	rear half of canopy disintegrated
6		1 Mar 69	split canopy
7		20 Sep 69	canopy split rail to rail
9		19 Mar 70	inadvertent jettison of rear canopy
10		25 May 71	inadvertent jettison by student
11		26 Feb 82	canopy cracked
14	CF100 (Canuck)	18 Oct 62	canopy slid back/undetermined cause
15		30 Jun 67	air pressure regulator failure
16		3 Aug 67	canopy slid back/external opening switch failure
18		29 Jun 71	canopy seal failure
19	CF101 (Voodoo)	22 Feb 62	inadvertent jettison by navigator
20		5 Nov 64	inadvertent jettison by navigator
22		21 Nov 68	inadvertent jettison by navigator
26		29 May 81	displaced canopy seal
28	CF116 (Freedomfighter)	6 Jul 78	canopy thruster improperly installed
29	CF104 (Starfighter)	3 Mar 63	canopy seal locking lever failed
30		8 Aug 63	canopy microswitch maladjusted
31		21 Jan 64	canopy striker bolt loose
32		25 Feb 64	canopy microswitch maladjusted
35		18 Nov 70	canopy seal rupture
36		27 May 71	canopy striker bolt maladjusted
39		2 Feb 74	maladjusted canopy warning switch
40		22 Jul 75	plexiglass separated from metal canopy
46	Sabre (F86)	27 Jul 63	canopy jettisoned/insufficient clearance seat adjustment and jettison handle
47		6 Jan 67	canopy jettisoned/flying clothing snag

Table 3. Slow Loss of Cabin Pressure

Case No.	A/C Type	Date	Cause
8	CT133 (Silver Star)	31 Oct 69	canopy seal failure
12	CF100 (Canuck)	16 Jan 62	undetermined (oxygen regulator u/s)
17		12 Feb 71	canopy seal jammed in canopy rail
21	CF101 (Voodoo)	28 Mar 66	cut canopy seal (oxygen regulator u/s?)
23		26 Jul 73	left rear canopy crack and torn seal
24		16 Jan 78	canopy seal rupture
25		22 Sep 78	canopy seal unseated
37	CF104 (Starfighter)	7 Apr 72	fibreglass FOD in fresh air scoop/ failure of rain remover valve
38		26 May 72	2 inch break in air duct
42	CT114 (Tutor)	18 Oct 68	undetermined
43		5 Dec 72	worn canopy seal
44		18 Dec 72	canopy seal leak
45		15 Jan 74	worn canopy seal from extreme cold

Table 4. Intermediate Rate of Loss of Cabin Pressure

Case No.	A/C Type	Date	Cause
13	CF100 (Canuck)	31 May 62	worn canopy seal
27	CF116 (Freedomfighter)	2 May 74	bent canopy closure switch activating arm
33	CF104 (Starfighter)	8 Apr 69	deactivated canopy closure activating switch
34		20 May 69	cabin air press. reg. failed, MC3M u/s
41		17 May 77	bent rear canopy bracket

Table 5. Oxygen Source and Description of Regulators

A/C Type	Source of Oxygen 1800 psi	Type of Regulators
CT133 (Silver Star)	Gaseous	ARO A20
CF100 (Canuck)	Gaseous	" A14 " A20 Bendix 2867/A2
CF101 (Voodoo)	LOX	Narrow panel made by ARO or Bendix
CF116 (Freedomfighter)	LOX	"
CF104 (Starfighter)	LOX	"
CT114 (Tutor)	Gaseous	"
F86 (Sabre)	Gaseous	Bendix D2

Table 6. Physiological Problems

Case No.	A/C Type	Altitude (Feet)	Problem	Diagnosis
1	CT133 (Silver Star)	15,000	Difficulty keeping eyes open in dust/wind	Nil
2		35,000	Painful ears	Otitic Barotrauma
3		35,000 (probably higher with aerodynamic suck)	Difficulty in communicating/noise, wind and pressure breathing	Nil
9		35,000 (descent to 10,000 for 30 min.)	Cold and painful eyes (pilot) minor face lacerations (nav.)	Cold injury Split visor
10		20,000	Cold and painful eyes	Cold injury
12	CF100 (Canuck)	38,000	Hot and cold flashes	Hypoxia
18		39,000	Difficulty breathing against oxygen under pressure	Nil
20	CF101 (Voodoo)	32,000	Pilot-painful ears Nav-bruised L-hand	Otitic barotrauma Injury from jettison lever
21		32,000	Light-headed	Hypoxia
24		25,000	Pain-left shoulder	D.C.S.
25		40,000 (cabin 30,000)	Pain-left arm	D.C.S.
26		37,000	Tingling left arm and knees	Hyperventilation D.C.S. ?
34	CF104 (Starfighter)	54,000	Felt ill, cold sweat, tingling behind knees	Hypoxia